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TDR-169(3210-02)TR-1

AC Stabilized Theta-Pinch

15 NOVEMBER 1963

Prepared by S. L. LEONARD and M. H. DAZEY
Plasma Research Laboratory

Prepared for COMMANDER SPACE SYSTEMS DIVISION
UNITED STATES AIR FORCE
Inglewood, California

LABORATORIES DIVISION • AEROSPACE CORPORATION
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ABSTRACT

An attempt ~~has been~~ WAS made to demonstrate the dynamic AC stabilization of the magnetic confinement of a plasma column in a theta-pinch apparatus capable of producing 250 kA. The stabilizing current was produced by the damped oscillating discharge of a specially fabricated 115 kV capacitor. No stabilizing effect was observed.

A second theta-pinch apparatus capable of producing currents of up to 400 kA has been used in further experiments. The dynamic behavior of the plasma produced in this device has been studied with the aid of streak photography, Kerr-cell photographs, and high-speed framing camera photographs. An unsuccessful attempt was made to stabilize the confinement of the plasma in this device, using the oscillatory discharge of a coaxial array of capacitors to provide the desired rf magnetic fields.

Spectroscopic studies of the plasma, including measurements of the ratio of the intensity of the D_β Balmer line to the intensity of the continuum, ~~have~~ yielded values for the electron temperature and electron (ion) density.

An account is given of attempts to develop a vacuum tube oscillator capable of producing stabilizing currents of the desired magnitude. The reasons for the abandonment of this effort are given.

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I. INTRODUCTION

In 1960 E. S. Weibel suggested that the confinement of a plasma by a magnetic field might be stabilized dynamically by the application of an rf magnetic field orthogonal to the confining field (Ref. 1). In his detailed theoretical investigation of this idea, Weibel considered the specific problem of the stability of the confinement of a cylindrical column of plasma by a purely longitudinal magnetic field and the effect of an azimuthal rf magnetic field on this stability. The theta-pinch experiments in the Plasma Research Laboratory have been motivated principally by the desire to provide an experimental test for this stabilization scheme.

In Weibel's theory the plasma was treated as a group of independent particles obeying the Vlasov equation. They were assumed to reflect specularly from the plasma-magnetic field boundary, which was assumed to be sharp and stationary. Under these conditions it could be shown that the confinement was neutrally stable and that the superposition of an azimuthal rf magnetic field would provide a positive restoring force for any distortion of the plasma-field surface.

In the Plasma Research Laboratory version of the theta-pinch, the confining longitudinal field is produced by a large azimuthal current flowing in a wide strap which encircles the cylindrical pinch tube (see Fig. 1). Typically, the low pressure gas in the pinch tube is pre-ionized by an initial axial discharge, and the main current is switched into the drive strap after the pre-ionization current has ceased to flow. The rapidly rising longitudinal magnetic field produced by the main current gives rise to a large azimuthal electric field in the gas. This field produces electrical breakdown and a large azimuthal current in the gas. The interaction between the longitudinal field and the plasma current compresses the plasma toward the center of the pinch tube, thus confining it away from the tube walls. The plasma-field geometry which results is a fair approximation to that postulated by Weibel in that there is a

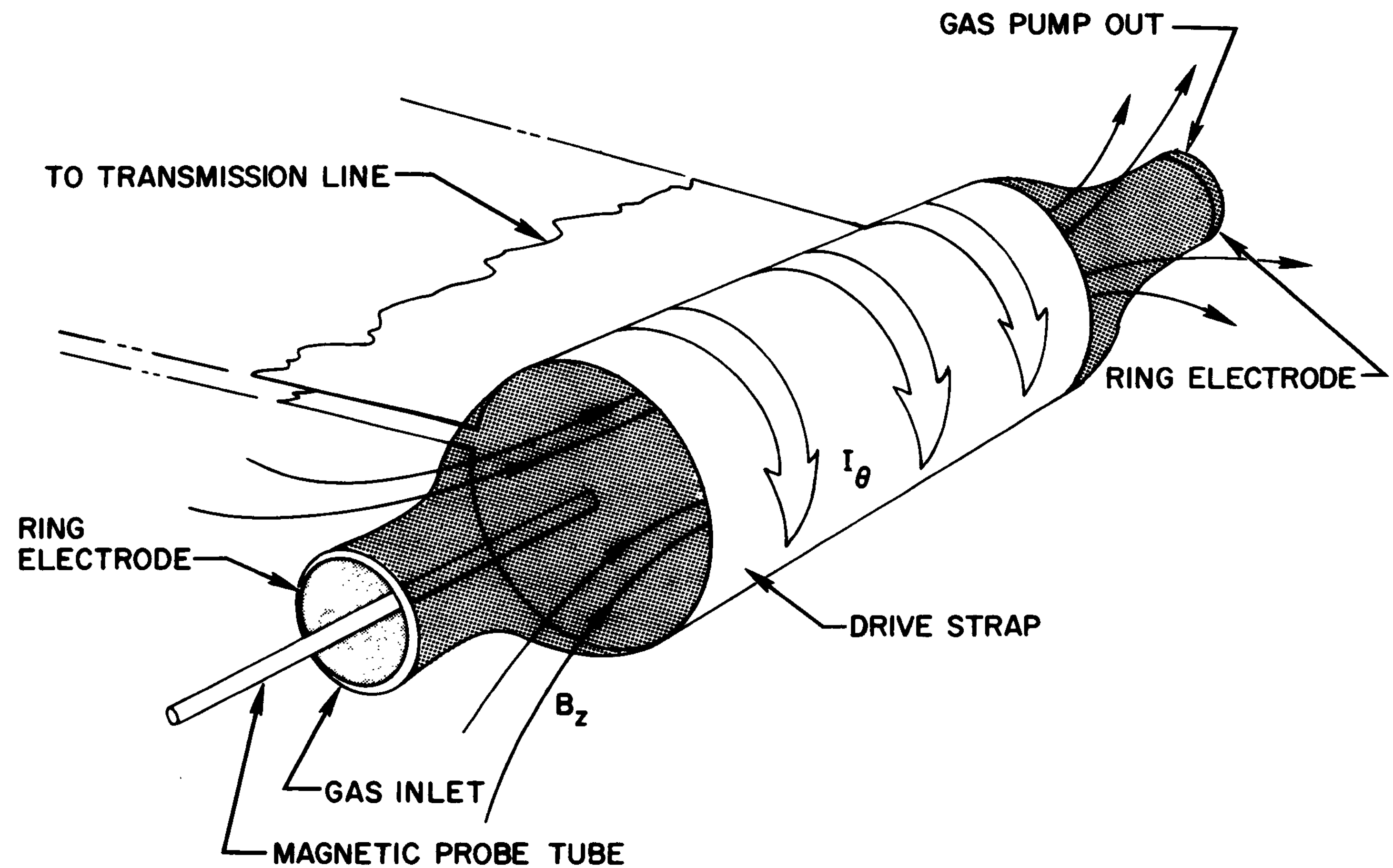


Fig. 1. Geometry of Theta-Pinch

cylindrical column of plasma confined by a longitudinal magnetic field with a fairly sharp plasma-field boundary.

In one important respect, however, the experimental situation outlined above does not correspond to the theoretical model. The plasma-field boundary is far from stationary. As the current in the drive strap increases, the plasma current sheath is compressed inward, heating and ionizing the gas as it progresses. The pressure inside the cylinder of plasma builds up and is reinforced by the axial magnetic flux which diffused through the current sheath during its formation period and was eventually trapped. The result is that the inward motion is stopped and reversed. The plasma-field boundary then oscillates radially about an equilibrium position defined by the inward pressure of the applied magnetic field and the outward pressure of the confined gas and trapped flux. Such an accelerating magnetic field-plasma boundary is not even neutrally stable, being subject to the Rayleigh-Taylor instability which here may be expected to result in the formation of longitudinal "flutes," by means of which the plasma escapes between field lines (Ref. 2). In spite of this failure of the experimental situation to satisfy rigorously the assumptions of the theoretical calculations, it was felt that the chances of producing stabilization of such a radially accelerating plasma-field boundary were great enough to warrant experimental investigation.

The theta-pinch experimental effort in this laboratory has been the subject of two previous reports. The first of these two reports (Ref. 3) includes a detailed description of the apparatus and an account of time-resolved studies of the plasma motion by means of magnetic probes and of Kerr-cell and streak photography. These pictures showed that for a range of pressures the plasma is indeed compressed as a cylinder and oscillates radially at a frequency which is consistent with several theoretical models (Refs. 4, 5).[†] It was shown that the dynamics of initial compression could be understood in terms of a phenomenological model described by Huddlestone (Ref. 6). As expected, the development of the "flute" instability was observed, the first flutes appearing during the second compression in the radial oscillation motion. At very high initial

[†]E. S. Weibel, private communication, 1960.

pressures, no radial oscillations were observed. When pre-ionization and main discharge were simultaneous, no instabilities were observed; but there appeared to be no real plasma confinement under these conditions and no discernible plasma field boundary (as indicated by magnetic probes).

In the second report (Ref. 7) a number of experiments designed to test the Weibel stabilization scheme are described. The theoretical considerations which place a lower limit of about 2 Mc on the rf frequency are discussed, as are some experiments which indicate that axial rf currents in the range of 10,000 to 20,000 A may be necessary to produce stabilization. In all the experiments described in Ref. 7, the rf currents were produced by "decrement oscillators," the oscillatory discharges of high voltage capacitors. These rf fields were applied to a deuterium plasma which had been selected as "standard," the initial pressure and other conditions having been selected to give a sharp plasma-field boundary while leaving the plasma dense and luminous enough for good photography. No stabilization effect was observed, although frequencies in the desired region (1.5 to 4.2 Mc) were reached, and large currents (3-14 kA) were obtained. However, the rf fields produced in this way damped so rapidly (to 1/e in two or three cycles) that these experiments could not be considered definitive tests of the stabilization scheme. Such definitive tests awaited the completion of a pulsed power oscillator, the development of which was described in another section of the report.

Also in Ref. 7 an account was given of some spectroscopic observations of the theta-pinch plasma under typical conditions. Measurements of the absolute continuum intensity and its variation with wavelength and of the Stark broadening of the D_{β} Balmer line yielded values for the electron temperature and the electron (ion) density. Confirmation of the electron temperature value was obtained by observing the ratio of the λ4568 He II line intensity to the intensity of the λ5875 He I line in a discharge in deuterium to which a small amount of helium had been added.

During the early stages of the experiments described in Refs. 4 and 7, the decision was made to construct a second theta-pinch apparatus (Apparatus II) capable of operation at higher voltage, with provision for possible later addition of magnetic mirror fields. It was felt that the higher voltage would produce a greater electron temperature and sharper plasma-field boundary as a result of a faster rate of increase of the current. Such a boundary would produce a still better approximation to the Weibel sharp-boundary model. The original apparatus (Apparatus I) could then be used in conjunction with the power oscillator development. After a long procurement delay, Apparatus II was finally assembled shortly after the end of the period covered by the earlier reports.

In Section II of this report, there is a discussion of a final decrement-oscillator experiment on Apparatus I. In Section III, Apparatus II is described. In Section IV, an account is given of the photographic and spectroscopic observations which have been made of the plasma produced in the new device. The results of the few decrement oscillator experiments performed on Apparatus II are presented in Section V. In Section VI, an account is given of the work on the development of the power oscillator. The conclusions and reasons for diversion of the theta-pinch effort away from the rf stabilization problem are given in Section VII.

II. EXPERIMENTS WITH APPARATUS I

The final experiments with Apparatus I involved an rf stabilization attempt in which the rf current was provided by a very high-voltage "decrement oscillator." The oscillator consisted simply of a capacitor-switch assembly (see Fig. 2) capable of being charged to 115 kV. The capacitance was only 8.95×10^{-3} μF, and the ringing frequency, when discharged through the theta-pinch plasma column, was 3.24 Mc. The maximum current, at the peak of the first half-cycle, was 14.7 kA, and the current damped to 1/e in 1.5 cycles. The capacitor consisted essentially of two concentric cylinders, the inner one being wrapped with a number of layers of mylar film. The outer cylinder, with its insulating extension, served as the outer electrode of the capacitor and as a pressure vessel containing SF_6 gas at 70-80 psi. As is evident from the figure, the spark-gap switch also operated in an atmosphere of high pressure SF_6. The trigger electrode was biased to a fraction of the voltage across the gap so that its tip was approximately at the same potential as the equipotential surface which would have existed at that point in the absence of the trigger electrode. The spark was initiated by an impulse which suddenly lowered the trigger voltage to ground potential.

The rf current produced by the 115 kV oscillator was applied to the pinched plasma in a number of experimental discharges, the rf being switched on at a variety of different times in the radial oscillation cycle. No change in the instability development was observed; discharges with and without the rf appeared identical in character. The experimental conditions were otherwise those of the earlier stabilization attempts, that is, D_2 gas at an initial pressure of 75 μ, 45 μsec delay between the beginning of the pre-ionization and the beginning of the main discharge, and 18 kV on the C-line array.

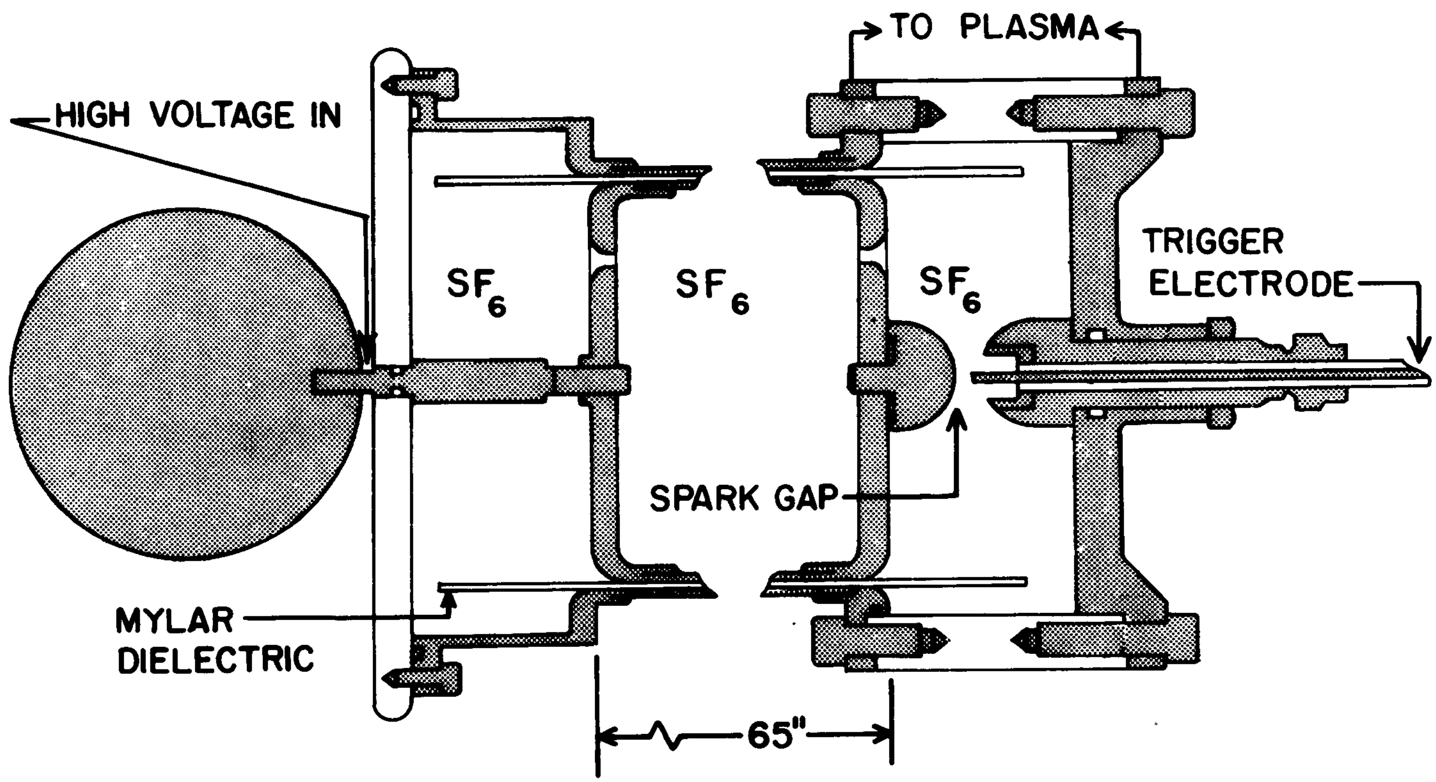
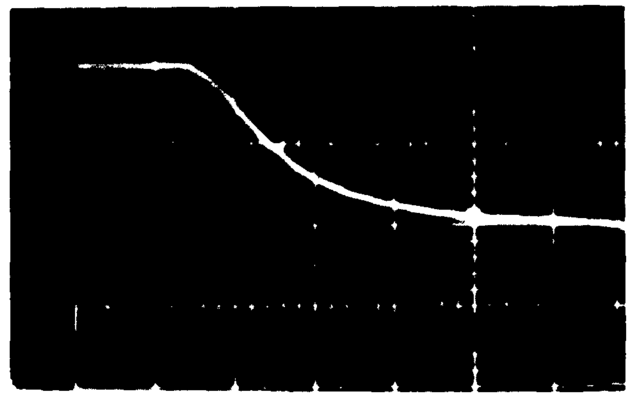


Fig. 2. 115 kV Decrement Oscillator

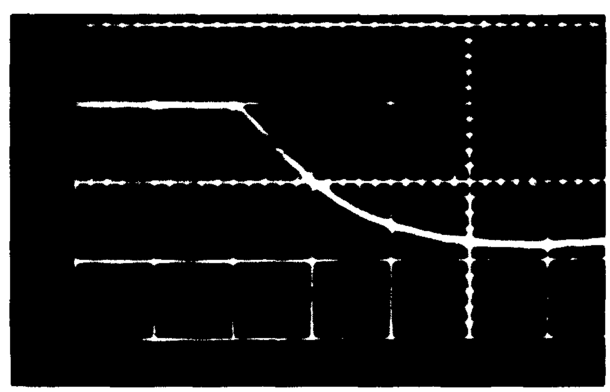
III. DESCRIPTION OF APPARATUS II

As in the earlier apparatus, the current in Apparatus II is provided by a group of four type-C transmission lines in parallel. Each line consists of four elements, each element providing one of the first four odd harmonics in the Fourier synthesis of the desired current wave-forms. The elements are capacitors connected to the drive strap by cables whose lengths are so chosen that the total inductance, coupled with the capacitance, produces the desired frequency. The output impedance of the four C-lines in parallel is 0.072 ohm. Apparatus II differs from its predecessor principally in that the C-lines can be charged to 30 kV instead of the earlier maximum of 18 kV. The peak current is thus increased from 250 to 415 kA with a corresponding increase in the confining magnetic field from 10 kG to ~14.8 kG. (The magnetic field increase is not strictly proportional to current, because the current-carrying strap is slightly wider in the new apparatus.)

The original design for the new apparatus provided for an ignitron switching arrangement in which the main current from the C-line was switched into the theta-pinch drive strap by means of four ignitrons in parallel, each capable of carrying the 100 kA provided by a single C-line. It proved possible to isolate the C-lines from each other during charging (by means of high-current nichrome damping resistors) so that an accidental breakdown in one ignitron would not result in the discharge of all the C-lines through a single ignitron. Jitter in ignitron firing was eliminated with some difficulty. Any remaining fixed time interval between firing time of the several ignitrons was so small as to produce no observable effect on the overall current wave-form. The wave form of the current in the drive strap (as measured by a magnetic probe at the center of the strap) was virtually identical with that obtained in Apparatus I except that the change in slope at the very beginning of the pulse was somewhat less abrupt (see Fig. 3), and the rise time was slightly greater.



(a) Wave Form with Ignitron Switching



(b) Wave Form with Spark Gap Switching

Fig. 3. Pinch Current Wave Forms

The first photographic observations of the plasma produced in the new apparatus revealed that no cylindrical plasma column was formed. Instead, a spirally rotating assemblage of luminous filaments was observed. In Fig. 4 are displayed some characteristic side-on and end-on views of the plasma as photographed through the Kerr-cell shutter. In each case, the shutter was opened at a time in the radial oscillation cycle when a very smooth cylindrical column of plasma would have been formed in Apparatus I.

Since the experimental goal was a study of the stabilization of a plasma column, no real investigation was made of this interesting phenomenon. The only significant change in the method of operation since the earlier experiments had been the introduction of ignitron switching. Therefore, it was decided to replace the ignitron array by a single open-air spark gap. Observations of the plasma produced when the current was switched by the spark gap quickly showed that a cylindrical column of plasma was again being formed. The difference in behavior may well be related to the differences in the abruptness of current onset for the two different switching methods, since this current onset must have an important effect on the gas breakdown and formation of a current sheath in the plasma.

The final arrangement of C-line cables, spark gap, and pinch tube is illustrated in Fig. 5. The blast shield is required to prevent the shock wave of the spark gap from striking the pinch tube. The horizontal member of this blast shield has been placed sufficiently low to permit the mounting of cylindrical capacitors adjacent to the pinch tube as required for the decrement oscillator described in Section V. A photograph of the pinch tube and spark gap arrangement is shown in Fig. 6. The gap is triggered by a discharge from the central insert electrode in the upper electrode structure to the electrode itself. The region around the gap has been left as open as possible to permit the enormous energy of the gap breakdown to be freely dispersed without any destructive effects. The pinch tube, as before, is a cylinder of pyrex with an OD of 4 in. and a wall thickness of 3/16 in. The drive strap is 13.5 in. in width.

(a) End View

(b) Side View

Fig. 4. Kerr-Cell Photographs of Plasma Produced by Ignitron-Switched Current

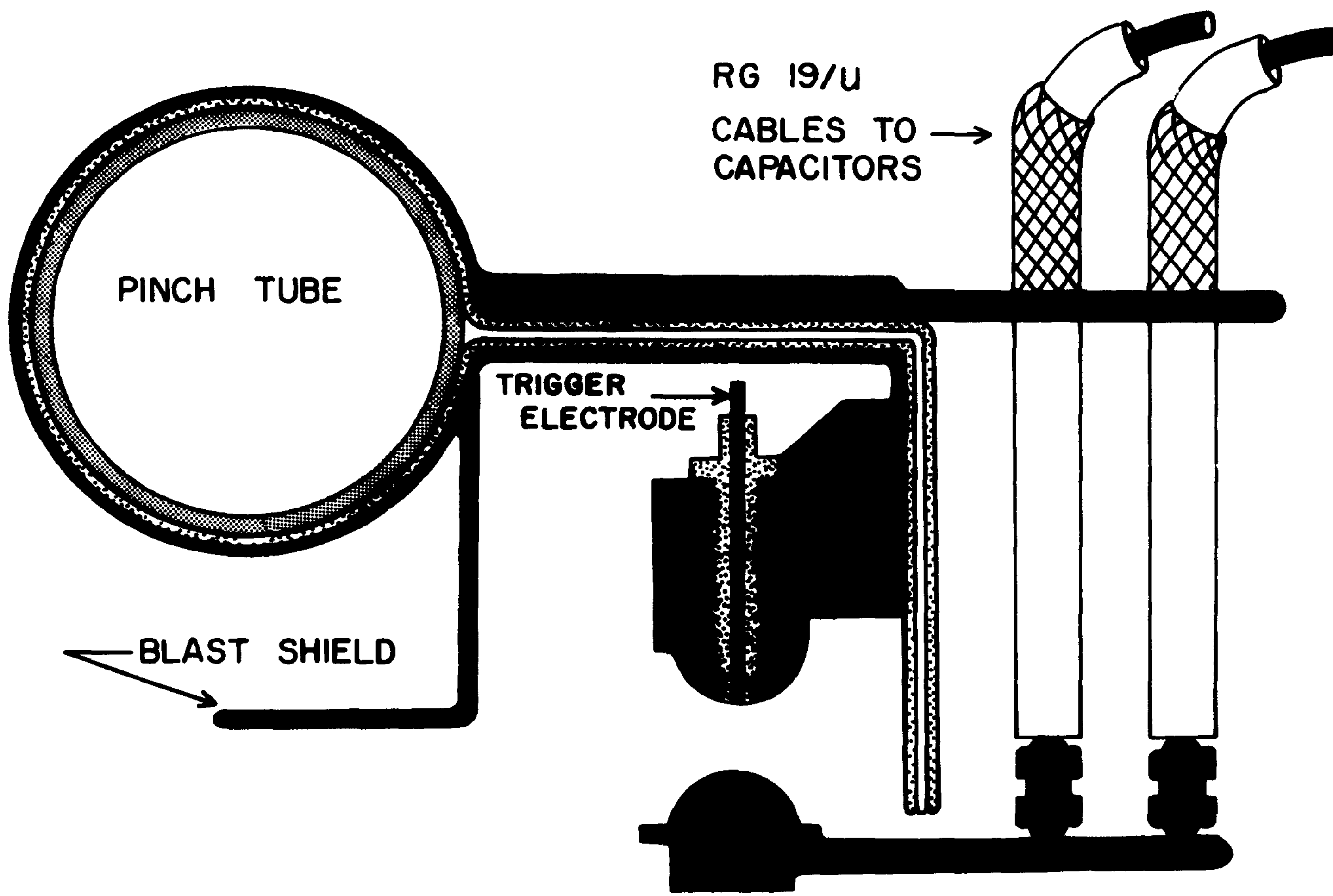


Fig. 5. Pinch Tube and Spark Gap Arrangement

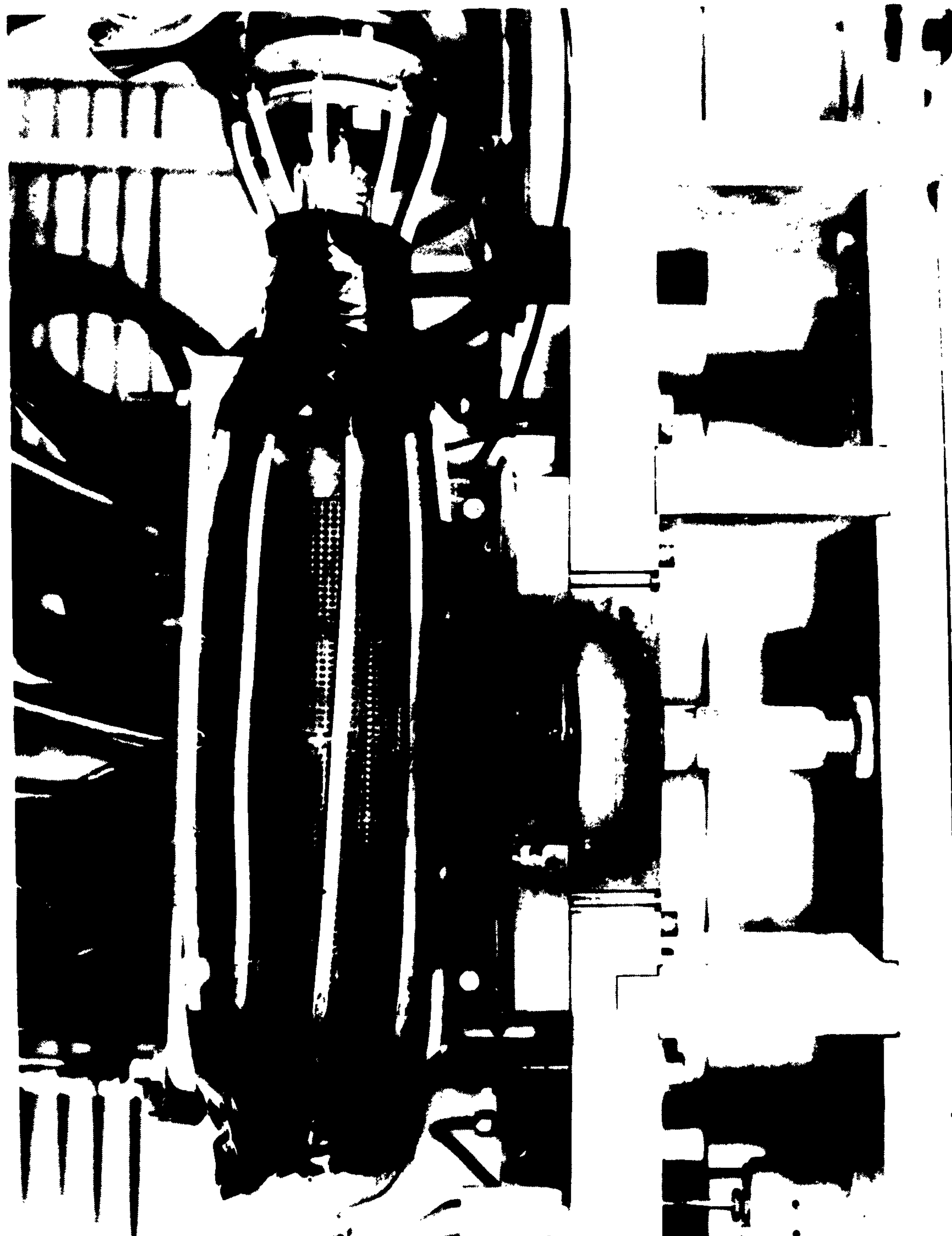


Fig. 6. Pinch Tube and Spark Gap

As in Apparatus I, the D_2 gas is admitted to the pinch tube through a heated palladium leak, to insure purity, and it is continuously flushed through the system. The system pressure is controlled by means of a throttling valve above the diffusion pump of the vacuum system.

Pre-ionization of the plasma is provided by the discharge through the gas of a 0.25 μF capacitor, charged to 18-20 kV. The discharge occurs between ring electrodes mounted at the ends of the pinch tube, the current being returned to one end by means of a set of wires mounted on the pinch tube to minimize inductance, as shown in Fig. 6. Pre-ionization currents of 4500-5000 A are typical.

IV. OBSERVATIONS

A. PHOTOGRAPHIC OBSERVATIONS

The plasma produced by Apparatus II has been studied by a variety of photographic techniques. A rotating mirror streak camera, operating at a writing speed of ~0.4 cm/μsec has been used to observe the time variation of the luminosity as viewed through a slit oriented perpendicular to the tube axis at the center of the pinch tube. A still camera mounted behind a very fast Kerr-cell shutter has been used to take highly time-resolved single photographs of the plasma column as viewed from one end. Finally, a rotating mirror framing camera operating at speeds as high as 5 frames per μsec has been used to take sequences of up to 25 frames, again viewing the plasma along the axis from one end.

Most of the work with Apparatus II has been devoted to a study of the D_2 plasma which results when the initial gas pressure is 75 or 100μ, where the interval between the beginning of the pre-ionization and the main discharge is ~45 μsec, and where the C-line high voltage is 25 or 30 kV. Under these conditions, the streak photographs show that, at least at the center, the plasma is rapidly driven toward the axis and oscillates radially at a frequency of about 1.4 Mc (Fig. 7). The oscillations die out after ~6 cycles, presumably because the magnetic field has fully penetrated the plasma and there is no longer a plasma-field boundary. The oscillation frequency agrees well with that indicated by a magnetic probe extending into the pinch tube along its axis and reaching either to the center or to the edge of the drive strap. The penetration of the plasma by the field in 3-4 μsec is indicated by the fact that the magnetic field on axis rises in that time to the maximum value it would have reached in the absence of gas in the discharge tube.

The Kerr-cell and framing-camera photographs (Fig. 8) show that the plasma under standard conditions is compressed toward the center as a symmetrical luminous column with a dark center. The dark center presumably represents

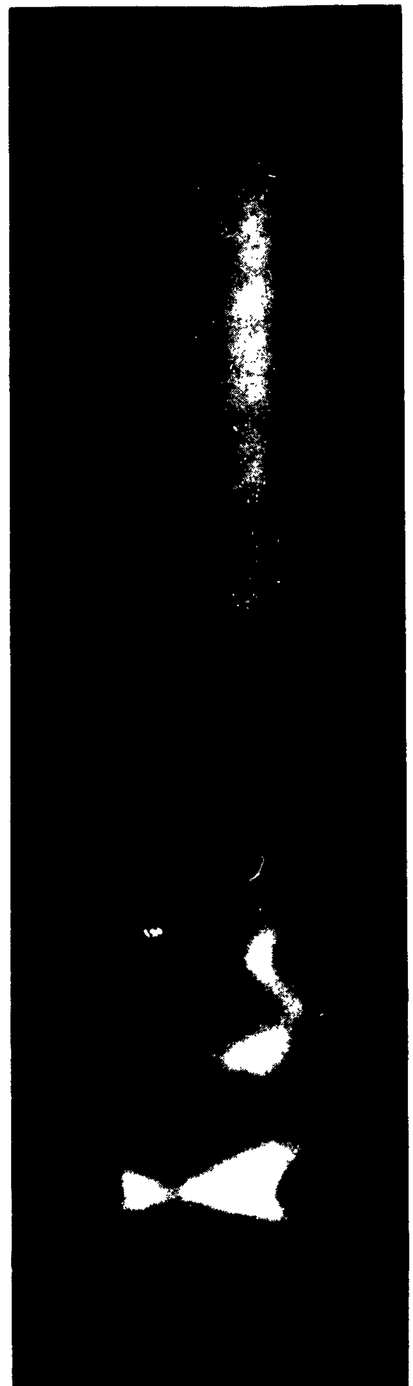


Fig. 7. Streak Photograph of Plasma of Apparatus II

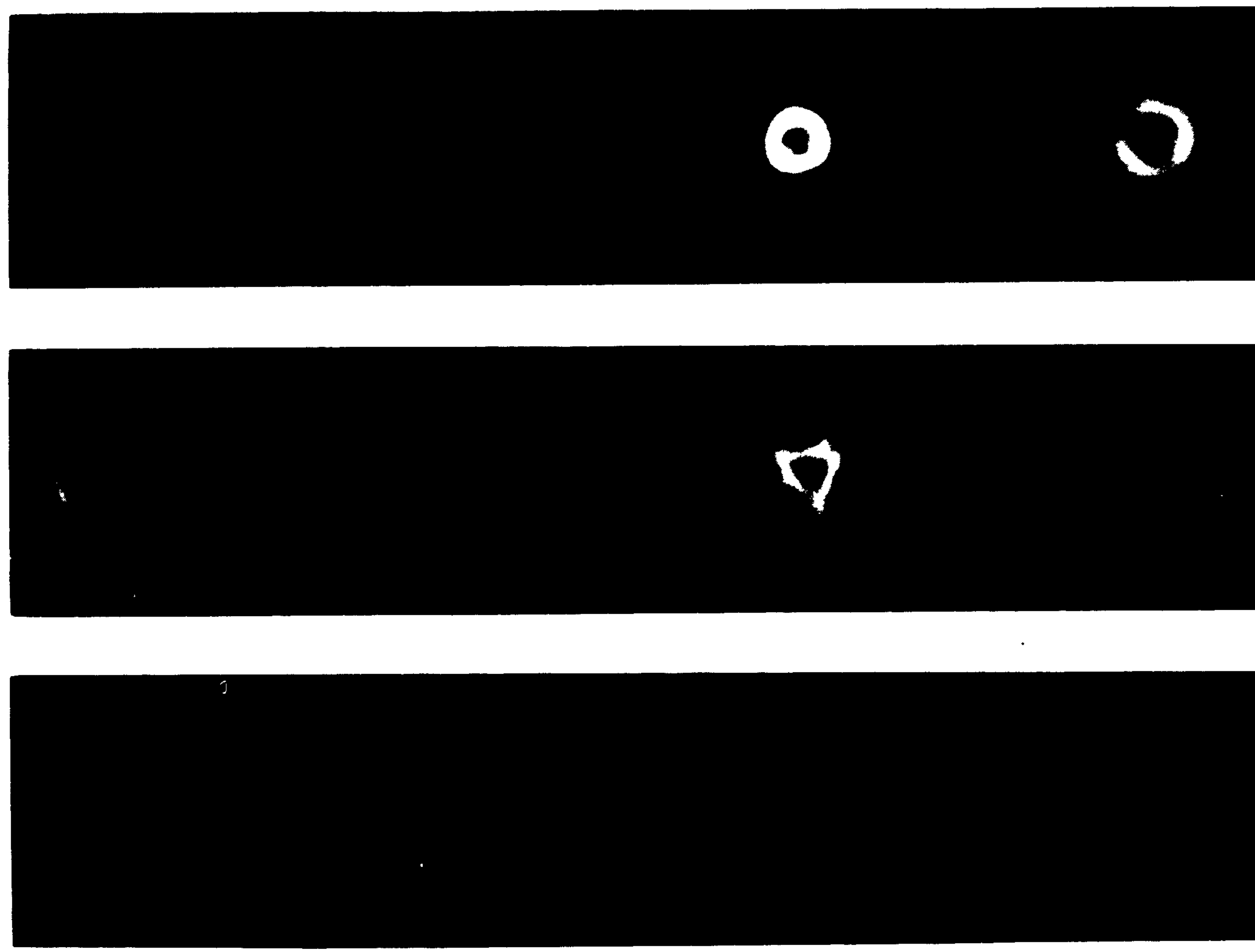


Fig. 8. Framing Camera Photographs - Initial Pressure 100μ

a region of low gas temperature and low luminosity, the outward pressure on the hollow plasma column being provided by trapped magnetic flux. After the first compression, the plasma relaxes outward in the course of the first radial oscillation, and ripples begin to appear on the outer plasma surface. These appear to be the expected flutes resulting from the Rayleigh-Taylor instability.

Photographs of plasmas formed when the initial pressure is higher, for example, 200 or 500 μ (see Figs. 9 and 10), show some differences. The radial oscillation frequency is reduced (as expected), and the initial compression is slower. In addition, ripples appear in the inner surface of the hollow plasma column, presumably indicating Rayleigh-Taylor instabilities of the inner trapped field-plasma boundary. Further, at 500μ, the very bright central spot is observed which had appeared in similar circumstances in experiments with Apparatus I. This bright spot on axis may represent intense heating as a result of converging shock waves driven ahead of the converging magnetic piston which compresses the plasma.

Somewhat different behavior has been observed in experimental discharges made when the delay between the beginning of the pre-ionization and the main discharge has been set at values appreciably less than 45 μsec. In these cases the initial converging plasma column has been more or less unsymmetrical, although the gas behavior is similar to that observed under standard conditions. The reasons for these differences have not been investigated since the major point of the experiment was the creation of a plasma with reproducible properties for stabilization experiments.

B. SPECTROSCOPIC OBSERVATIONS

Spectroscopic observations of the plasma produced in Apparatus II have included (1) an investigation of the time of appearance of the principal impurities, (2) time resolved measurements of the ratio of the intensity of the D_β Balmer line to that of the nearby continuum, and (3) absolute continuum intensity measurements.

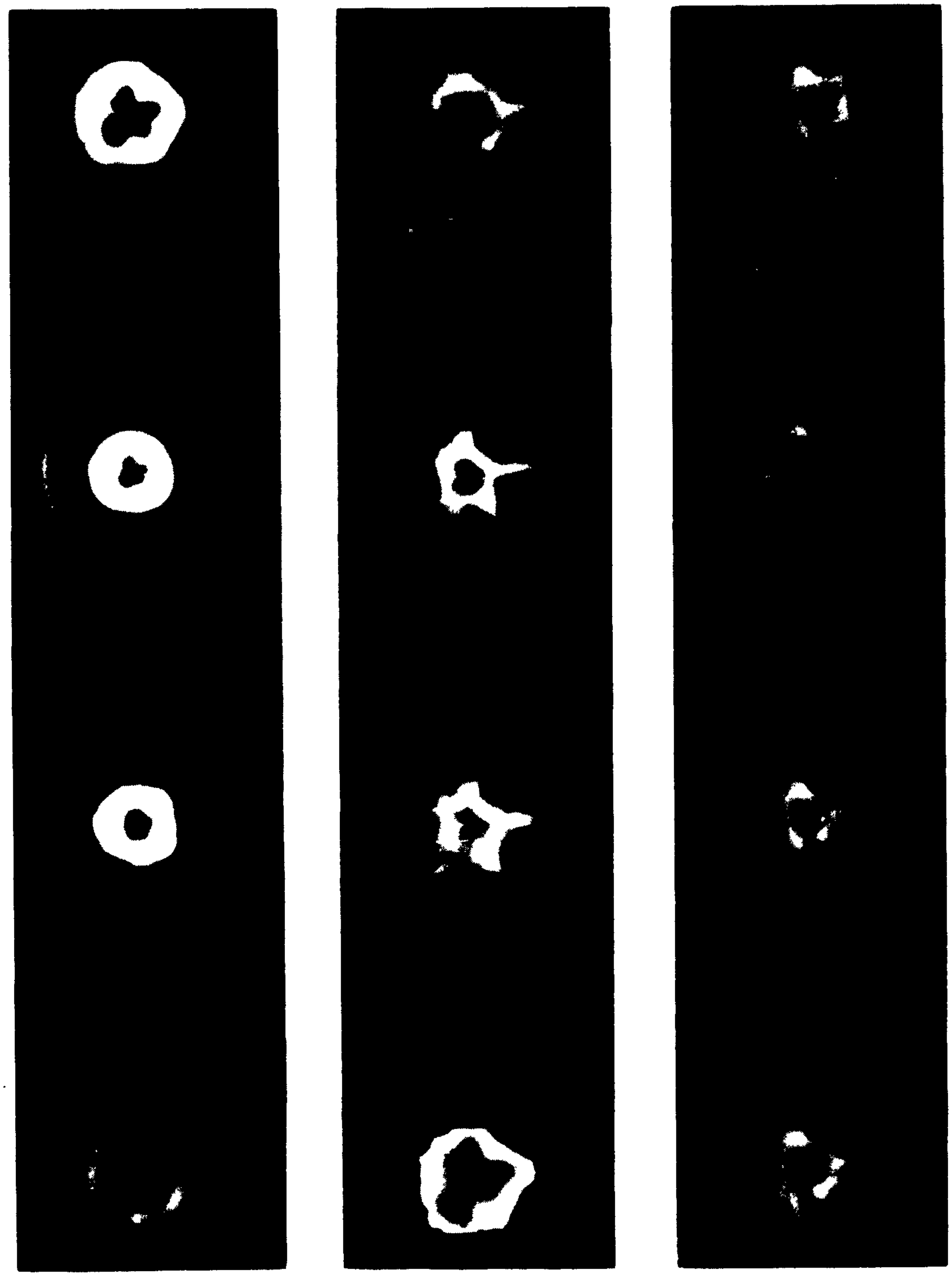


Fig. 9. Framing Camera Photographs - Initial Pressure 200μ

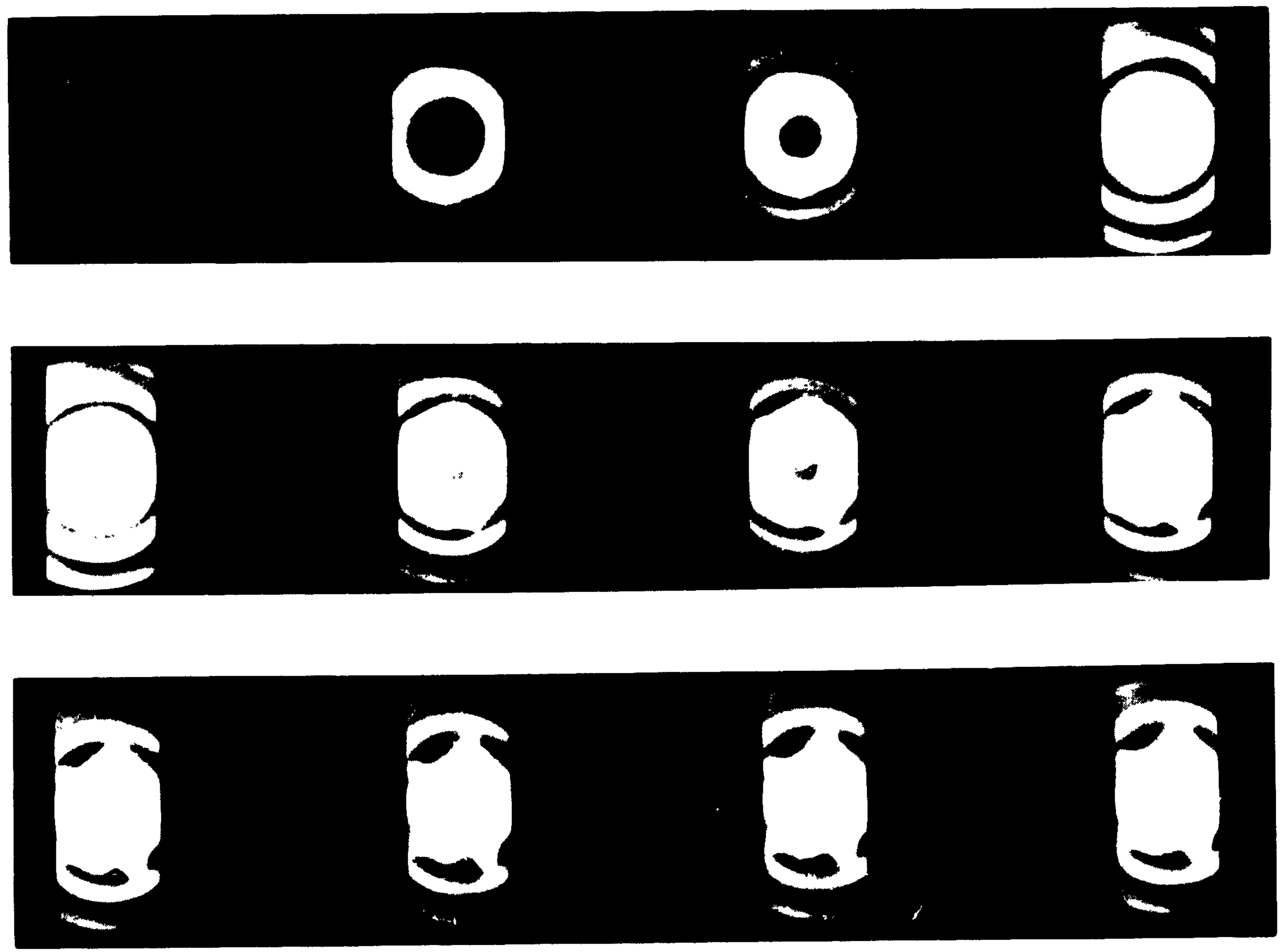


Fig. 10. Framing Camera Photographs - Initial Pressure 500μ

Preliminary time integrated spectra of the discharge were obtained with the aid of a 1.0 meter Bausch and Lomb spectrograph with photographic recording. The principal impurities were found to be C II, C III and O II. Several of the most prominent of the lines of these elements were then studied in time-resolved fashion by means of a 0.5 meter grating monochromator with photomultiplier readout. None of the impurity lines studied became more intense than the continuum background until at least the second half-cycle of the main pinch current. It thus appears that impurities do not make significant contributions to the light emitted by the plasma during the first half-cycle of the discharge, the only time interval of interest in this experiment.

Time-resolved information about the ratio of the intensity of the D_β line to that of the nearby continuum has been obtained with the aid of the 0.5 meter monochromator. Since the D_β line is highly broadened during the periods of high plasma compression, it has been necessary to make a large number of experimental observations, obtaining intensity information about only a small wave length interval (typically $\Delta\lambda \sim 1.6$ Å) from each separate experimental discharge. Correction for shot-to-shot variations has been made possible by the simultaneous observation of the same region of the discharge (by means of an optical beam-splitter) using the 1.0 meter grating spectrograph equipped with photomultiplier readout ead. This latter spectrograph was used to observe two wavelength intervals of about 8 Å each, centered near the peak of D_β and in the continuum at about 5200 Å. Since the continuum intensity is relatively insensitive to electron temperature, monitoring the continuum intensity permits a rough correction of the monochromator reading for variations in electron density. Since the D_β intensity is quite sensitive to T_e, monitoring the D_β intensity makes possible a rough correction of the monochromator reading for variations in T_e.

The corrected monochromator readings were plotted against $\Delta\lambda = \lambda - 4860$ on semi-log paper. Comparison of these plots with those expected on the basis of the theory of Griem, Kolb, and Shen (Refs. 8, 9, and 10) for various values of

n_e permitted the determination that $n_e = 8 \times 10^{16}$ cm^{-3} to an accuracy of about 15 percent. In Fig. 11 a typical set of observations, now plotted to a linear scale, is displayed. The curve is a theoretical one, based on the Griem, Kolb, and Shen calculations for $n_e = 8 \times 10^{16}$ cm^{-3}, normalized for optimum agreement with experiment. If the area under this best-fit theoretical curve is used as a measure of the D_β intensity (Ref. 11), the resulting value of the D_β/continuum ratio corresponds to an electron temperature of 3.9 ± 0.2 eV.

Figure 10 shows that near the center of the line the intensity is much larger than that indicated by the best-fit theoretical curve. This additional intensity is believed to be the contribution of a cooler outer layer of plasma of lower electron density.

Observations of the intensity of the continuum radiation at several different wavelengths were also made with the monochromator. Absolute values were obtained when the photomultiplier readout was calibrated against a ribbon filament standard lamp obtained from the National Bureau of Standards. From these absolute intensity values, assuming an electron temperature of 4 eV, an electron density value of 8.0×10^{16} cm^3 was obtained. The agreement between this value and that obtained from the D_β broadening is therefore excellent.

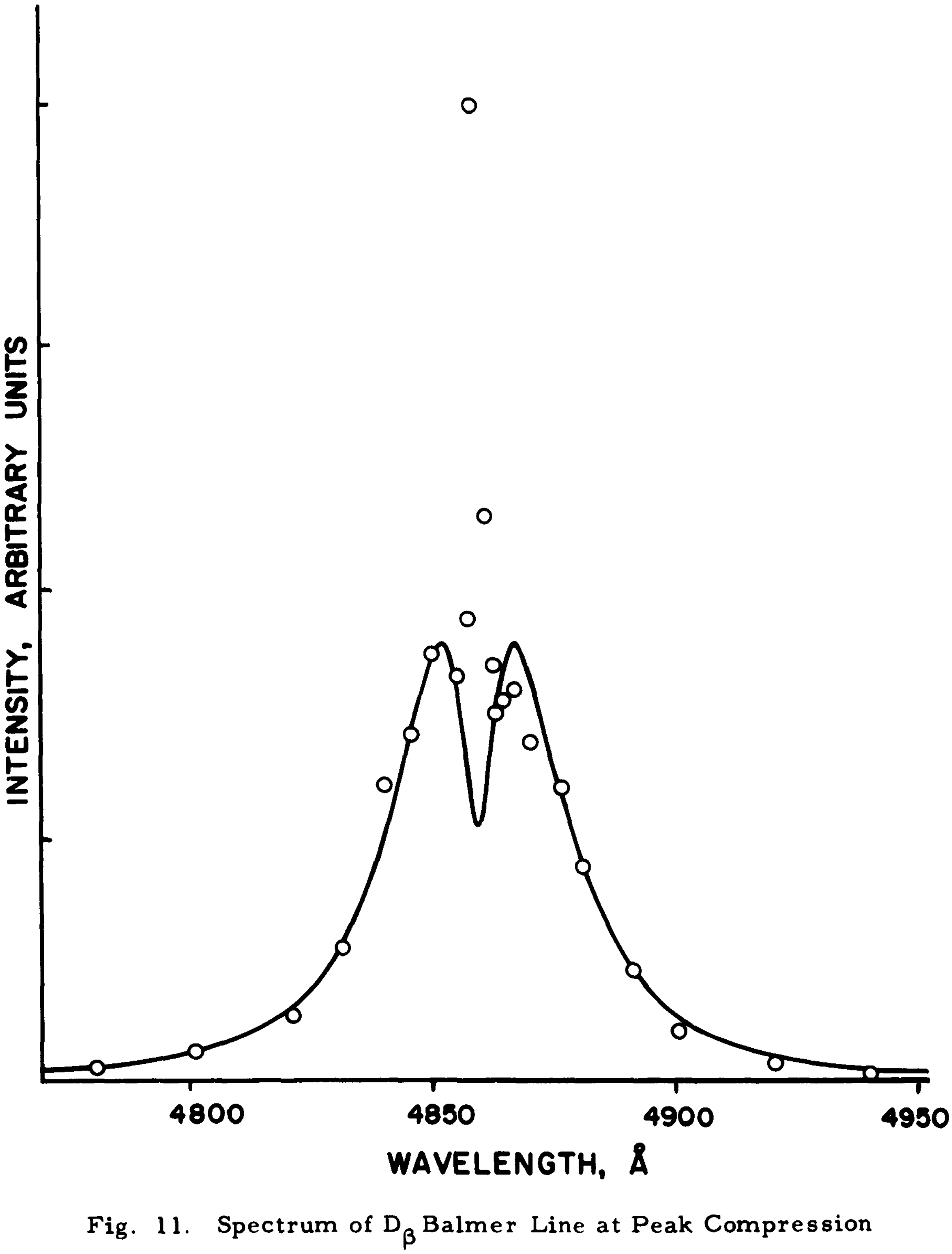


Fig. 11. Spectrum of D_{β} Balmer Line at Peak Compression

V. DECREMENT OSCILLATION EXPERIMENTS

In view of the great similarities in properties and behavior between the plasma of Apparatus I and that of Apparatus II, simple repetition of the earlier attempts to produce rf stabilization by means of decrement oscillators did not seem worthwhile. Accordingly, the only decrement oscillator experiments were performed with an oscillator operating at higher frequency than those used previously, with a corresponding reduction in maximum current. This oscillator was essentially identical in external configuration to oscillator E, the coaxial arrangement described on page five of Ref. 6. The total capacitance, however, was only 0.005 μF, and the rf frequency was 6.5 Mc. The oscillator was operated at a voltage of 55 kV and produced a current of maximum value 2500 A, damping to 1/e in about 2 cycles. This rf current produced no detectible stabilizing effect on the plasma as observed by Kerr-cell photography. The instabilities developed in the same manner and at the same point in the radial oscillation cycle, independent of the presence or absence of the rf. This negative result was obtained regardless of the time in the radial oscillation cycle at which the rf was switched on.

VI. POWER OSCILLATOR DEVELOPMENT

At the beginning of the rf stabilization program, it was felt that rf currents of from 1000 to 4000 A would be sufficiently large to provide a measurable amount of stabilization because of the neutral stability of the pinched plasma in the absence of accelerations. Therefore, it appeared that a 1 Mw oscillator, developed around an RCA 2581A electron tube, should be suitable for generating the required rf current for a wide range of plasma impedances. As previously mentioned, there are experimental indications (described in more detail in Ref. 7) that rf currents of from 10 to 20 kA will be necessary to produce observable stabilization. Such large currents can be achieved with a 1 Mw oscillator only if the total circuit resistance through which the rf current must flow can be made very small. For a given power, P, in watts, the maximum allowable total rf circuit resistance is given by

$$R = P/2I^2$$

where R is the resistance in ohms, and I is the peak current in amperes. For a peak current of 1000 A, R must be less than 0.5 ohm, while for currents of 10,000 A, R must be smaller than 5 milliohms.

The impedance of the plasma column itself can be estimated on the basis of the measured plasma temperature and density. The plasma resistivity can be obtained from Spitzer's formula (Ref. 12)

$$\eta = 6.53 \times 10^3 \ \ln \Lambda / T^{3/2} \text{ ohm-cm}$$

where T is the electron temperature in $^{\circ}$K, and $\ln\Lambda$ depends on electron temperature and density. For an electron temperature of 40,000°K and an electron density of 8×10^{16}, $\ln\Lambda$ is about 5, and the plasma resistivity is then about 4×10^{-3} ohm-cm. If the length of the current path in the plasma is taken to be 70 cm and the diameter of the plasma column to be 2 cm, the total plasma resistance is $\sim$0.1 ohm. The AC resistance would be somewhat higher because of skin effect. If the total resistance in the rf circuit were 0.1 ohm, then the maximum current obtainable from a 1 Mw oscillator would be only 2200 A. The observed damping of the rf currents produced by the various decrement oscillators has permitted an independent determination of the total plasma resistance. Corrections for the switch impedance have been made possible by auxiliary experiments in which the decrement oscillator capacitors have been discharged through metal conductors. The corrected values for total plasma resistance obtained in this way have all been at least four times as great as the value calculated from electron temperature and density. The maximum current obtainable from a 1 Mw oscillator thus appears to be under 1000 A.

It is believed that the discrepancy between the calculated and measured values for plasma resistance may be caused by the existence of a region of higher resistivity in the immediate vicinity of the cold electrodes. Some effort has been devoted to an attempt to reduce the plasma-electrode resistance by varying the electrode shape. The results have been inconclusive because of the small number of electrode shapes tested and the relatively large amount of series resistance in the air-gap switches used to switch current from decrement oscillators into the plasma. A more exhaustive effort to reduce the plasma-electrode resistance would probably require the development of methods of switching high currents with switch resistances of 5 milliohms or less.

Another serious problem has arisen in connection with the oscillator itself. It has proved impossible to operate the device at power levels anywhere near the expected values. After an exhaustive investigation, it became clear that this effect could not be explained in terms of circuit deficiencies. Attention was then turned to the tube itself. A special pulser was fabricated which had the capability of testing the DC characteristics of the RCA 2581A electron tube to the full expected capacity of the tube. The DC tests, later confirmed by Radio Corporation of America, indicated that the maximum possible current from the tube under rf conditions would be ~50 percent of the previously expected value. According to information obtained informally, the RCA 2581A tube had never actually been tested at its full rated levels; the operating conditions supplied by the manufacturer were extrapolations from results of tests at lower levels.

This new information about the actual capability of the RCA 2581A tube makes it clear that a 1 Mw oscillator which uses this tube is not possible; in fact, the maximum obtainable power is of the order of 0.25 MW. Since such an oscillator would not be capable of producing a current of more than 1000A with a 0.1 Ω plasma load, further work with the RCA 2581A tube was discontinued.

VII. CONCLUSIONS

It is clear from the preceding report and those issued earlier that the results of the rf stabilization experiments using decrement oscillators have been uniformly negative. It is difficult to see any way of extending significantly the range of such oscillators either in frequency or maximum current. Hopes of developing a 1 Mw air-cooled power oscillator, based on the RCA 2581A tube, also appear to be vain. Further, even if the 1 Mw oscillator were available, it seems certain that the power would be too small, in view of the large effective impedance of the plasma.

Therefore, any further work on rf stabilization would seem to require (1) the development of a pulsed power oscillator in the 5-10 Mw range, and (2), the reduction of the effective impedance of the plasma to a considerably smaller value. Since both problems would have to be solved and since the first would require a considerably increased effort in terms of money and manpower, it has seemed wise to abandon the rf stabilization attempt. This decision is reinforced by the knowledge that a considerably more powerful oscillator has in fact been designed for this very purpose and is nearing completion in the Laboratoire de Recherches sur Physique des Plasmas at Lausanne, Switzerland.[†]

The role of the theta-pinch apparatus in the Plasma Research Laboratory has, therefore, gradually shifted away from the rf stabilization experiments toward participation in the Laboratory's considerably increased program in plasma diagnostics. The theta-pinch apparatus produces a fairly hot, dense plasma whose emission in the far infrared region of the spectrum is being investigated. Plans call for an extension of this work and for further diagnostic studies of the plasma radiation in other regions of the spectrum.

[†]E. S. Weibel, private communication, 1963.

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15 November 1963. [35] p. incl. illus.
(Report TDR-169(3210-02)TR-1; SSD-TDR-63-219)
(Contract No. AF 04(695)-169) Unclassified report

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